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The following topics were studied in detail during the report period:

1) Combined volume and surface scattering in a channel, using a modal formulation.

2) Two-way formulation to account for backscattering in a channel.

3) Data analysis to determine vertical and horizontal correlation lengths of the random index-of-refraction fluctuations in a channel.

4) The effect of random fluctuations on the two-frequency coherence function in a shallow channel.

5) Approximate eigenfunctions and eigenvalues for linear sound-speed profiles.

6) The effect of sea-water absorption on scattering in a shallow channel.

Topics 1-5 were reported upon in the previous progress report (Jan. 1, 1994- Oct. 31, 1994) and the progress we have made is updated in this report. The work on topic 1 has been completed and a paper was submitted to JASA in December 1994. Topic 6 is a new topic. All topics are discussed in the following sections.

1. Combined volume and surface scattering in a channel using a modal formulation.

On Dec. 16, 1994 a paper was be submitted to JASA on this subject. A copy of this paper was sent to Dr. Badiey when the paper was submitted for publication. The abstract of the paper is:

Combined Volume and Surface Scattering in a Channel Using a Modal Formulation

by

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In previous work, a modal approach was used to study random volume scattering in a shallow channel (M.J. Beran and S. Frankenthal, J. Acoust. Soc. Am., 91, 3203-3211, 1992). Here, we show how to include the effects of a rough channel surface in the formulation. To include the effects of a rough surface, we take the modes to be dependent on the range and transverse coordinates in addition to the depth coordinate. The propagation is studied in terms of the ensemble-averaged two-point coherence function and the equation governing the coherence function is derived. The general method is given in the above-cited article on volume scattering. In the present paper, we show how the surface scattering terms may be treated using the modal approach. In order to insure energy conservation when the generalized modal field equations are simplified, the parabolic approximation is replaced by a method which includes both forward and backward propagating fields.

The two-point coherence function is expressed as the sum over both self-modal and cross-modal coherence functions. We consider the difference between the equations governing the self-modal coherence functions and the cross-modal coherence functions. We present a numerical example which uses typical shallow water parameters. Figures are presented to show how the mode energies are transferred between the modes as the acoustical field propagates. The difference between the modal transfer of energy for volume scattering and for surface scattering is discussed.

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2. Two-way formulation to account for backscattering in a channel.

In the analysis performed on the combined volume and surface scattering, it was found that the addition of the surface scattering caused the conservation of energy to be violated. It was found that the violation occurred because backscattering was not properly taken into account. A proper formulation was developed based on an analysis given in the book by C.A. Boyles, (Acoustic Waveguides, Applications to Ocean Science, Interscience, John Wiley and sons, 1984).

Since the last progress report we have developed the method further. We have compared the functional integration derivation with the method we have used to derive the coherence equations and found comparable results. We find, however, that in the general case where the initial acoustic signal is beamed that we obtain integro-partial differential equations rather than partial differential equations. At present we are investigating numerical techniques to solve these more complex equations.

An abstract will be submitted to the May ASA meeting in 1995 and we will include the abstract in the next progress report.

3. Data analysis to determine vertical and horizontal correlation lengths of the random index-of-refraction fluctuations in a channel.

The following abstract is a draft of the abstract that will be submitted to the May ASA meeting in 1995:

Determination of vertical correlation lengths in a channel using SWELLEX-2 thermistor data

by

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In order to properly determine the volume scattering in a channel, it is necessary to know the characteristic vertical and horizontal correlation lengths associated with the random index-of-refraction fluctuations. Here we discuss the results we have obtained for characteristic vertical correlation lengths using SWELLEX-2 vertical-array thermistor data. The data has been

analyzed for day-time and night-time observations. In addition the results are dependent upon averaging times and this effect is discussed. Graphs are given for the standard deviation and normalized cross-correlations of the fluctuations, as a function of depth.

Note: This data was supplied to us by Dr. Pacewark of NRL.

4. The effect of random fluctuations on the two-frequency coherence function in a shallow channel.

We previously reported on the derivation of the equations governing the coherence function for the two-frequency case when the frequency difference was not too small. In this report period we have been seeking to develop a method which allows a smooth transition to the zero frequency difference case. It appears, however, that in this case we shall need to use difference equations rather than differential equations as the governing equations. As we stated in the last report we expect to complete the numerical calculations for the former case by the spring of 1995.

5. Approximate eigenfunctions and eigenvalues for linear sound-speed profiles.

In the paper in Sec. 1, numerical calculations were included for a constant sound-speed profile. The same calculations will be done for a linear sound-speed profile. Since the last report Mr. Barnard, the Ph.D. student, has obtained a more accurate solution for the very low-number modes. His results have also been compared to work in which the wavenumber rather than the sound speed is linear.

In the next month Mr. Barnard will present his Ph.D. research proposal to the Electrical Engineering faculty at The Catholic University of America.

6. The effect of sea-water absorption on scattering in a shallow channel.

We are presently completing the numerical calculations to determine the effect of sea-water absorption. All the theoretical calculations have been completed. Except for the section on numerical calculations a paper on the subject has been written and we present below a draft of the abstract.

The effect of sea-water absorption on scattering in a shallow channel

by

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At frequencies above 5-10 kHz sound absorption by seawater becomes of importance for propagation ranges of tens of kilometers in shallow channels. In previous work we have shown how to calculate the effect of volume and surface scattering in a channel using a modal coherence formulation. Here we wish to show how to simply extend the formulation to include the effect of sound absorption. The effect of absorption is mode dependent and prevents the modal energy distribution from reaching an equilibrium state. We conclude the paper by presenting a series of numerical calculations when surface scattering is the dominant effect. We show how the modal energy distribution is effected by absorption as the sound frequency increases.